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Improvements in, or Relating to, VDSL

The present invention relates to a method of VDSL zipper transmission system in which VDSL transmissions over a common cable may be time asynchronous, a transmission system employing the method, a receiver for use with the transmission system and a transmitter for use with the transmission system.

Our co-pending patent application WO 9706619 describes a procedure for suppressing near-end crosstalk (NEXT) at bidirectional communication in wire networks involves different subcarriers are used in the two transmission directions, at which the subcarriers are orthogonal. Preferably a number of subcarriers are transmitted in each transmission direction. Every other subcarrier is used in respective direction. A number of subcarriers are used, the number of carriers which are used in one transmission direction is larger than in the other transmission direction.

In our co-pending patent application, referenced above, Zipper VDSL is the basic concept with time synchronizing. The present invention is intended to complement the earlier invention so we can use the Zipper patent without time synchronizing. Two methods for increasing the efficient are also mentioned.

Zipper is a time-synchronized frequency-division duplex implementation of discrete multi tone (DMT) modulation. Two communicating Zipper modems transmit DMT symbols simultaneously with a common clock. The Zipper scheme implies that every carrier, in the total set of carriers in the DMT signal, is exclusively chosen to be used for either the up-stream or the down-stream direction. When all transmitters are time synchronized, the near end cross-talk (NEXT) and near end echoes injected into the received signal are orthogonal to the desired signal. To ensure the orthogonality between the signal and all the noise sources originating from DMT signals in the opposite direction, the guard time with cyclic extension of the symbols between consecutive symbols must be dimensioned for the maximum propagation delay of the channel. Further, the size of the guard time is minimized by applying

timing advance.

According to a first aspect of the present invention, there is provided a telecommunications transmission system using zipper having at least two VDSL systems, each of said VDSL systems comprising a pair of zipper modems communicating over a cable transmission path, said at least two VDSL systems employing a common cable, characterised in that said telecommunications transmission system is adapted to:

- handle zipper transmissions transmitted over said common cable;
- at least partly mitigate NEXT; and
- permit transmissions in a first VDSL system which are asynchronous with transmissions in at least a second VDSL system.

DMT frames may be pulse shaped prior to transmission.

Said pulse shaping may produce an improved suppression of side lobes of said DMT's spectrum.

Said pulse shaping may be produced by forming pulse shaped wings on a DMT frame in cyclic extensions of the DMT frame.

Said pulse shaped wings may be in the form of a raised cosine pulse.

Said pulse shaping may be performed at a transmitter after addition of a cyclic extension to a symbol and prior to digital to analogue conversion.

A DMT signal received by a receiver may be windowed to further reduce NEXT.

Said windowing may be performed by:

- multiplying μ samples at the beginning and end of a block of 2N+μ samples;
- folding and adding μ/2 samples from the beginning of the 2N+μ block of samples to the end of the 2N remaining samples; and
- folding and adding μ/2 samples from the end of the 2N+μ block of samples to the beginning of the 2N remaining samples.

According to a second aspect of the present invention, there is provided, in a telecommunications transmission system using zipper and having at least two VDSL systems, each of said VDSL system comprising a pair of zipper modems communicating over a cable transmission path, said at least two VDSL systems employing a common cable, a method of transmission characterised by permitting zipper transmissions of said first and, at least, said second VDSL transmission systems, to be transmitted over said common cable, where transmission in said first VDSL system are asynchronous with zipper transmission in said second VDSL system and in which the effects of NEXT are, at least partly, mitigated.

DMT frames may be pulse shaped prior to transmission.

Said pulse shaping may produce an improved suppression of side lobes of said DMT's spectrum.

Pulse shaped wings may be formed on a DMT frame in the cyclic extensions of the DMT frame.

Said pulse shaped wings may be formed as a raised cosine pulse.

Said pulse shaping may be performed at a transmitter after addition of a cyclic extension to a symbol and prior to digital to analogue conversion.

A DMT signal received by a receiver may be windowed to further reduce NEXT.

The following steps may be used to perform said windowing:

- multiplying μ samples at the beginning and end of a block of 2N+μ samples;
- folding and adding μ/2 samples from the beginning of the 2N+μ block of samples to the end of the 2N remaining samples; and
- folding and adding μ/2 samples from the end of the 2N+μ block of samples to the beginning of the 2N remaining samples.

According to a third aspect of the present invention, there is provided a transmitter, characterised in that it is adapted for use with a telecommunications system as described in any preceding paragraph , or to use a method as described in any preceding paragraph.

According to a third aspect of the present invention, there is provided a receiver, characterised in that it is adapted for use with a telecommunications system as described in any preceding paragraph , or to use a method as described in any preceding paragraph.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 illustrates the disturbing signals that affect the orthogonality of zipper.

Figure 2 illustrates sampling at the VTU-O side of received frame disturbed by frames from near end transmitters.

Figure 3 illustrates DMT transmitter/receiver pair for down-stream transmission, exemplifying symmetric communication where every second sub-carrier is used for the up (u) respective down-stream (d) directions.

Figure 4 illustrates the frame format of zipper.

Figure 5 illustrates non-orthogonal NEXT.

Figure 6 illustrates pulse shaping of the DMT frame.

Figure 7 illustrates pulse shaping in the transmitter and windowing n the receiver.

Figure 8 illustrates windowing of a received DMT frame.

Figure 9 illustrates asynchronous non-orthogonal NEXT with and without windowing and pulse shaping.

In the following we have a description of our earlier patent application on Zipper VDSL in the basic concept with time synchronizing. The invention is intended to complement the earlier invention so we can use the Zipper patent without time synchronizing. Two methods for increasing the efficient are also mentioned.

Zipper is a time-synchronized frequency-division duplex implementation of discrete multi tone (DMT) modulation. Two communicating Zipper modems transmit DMT symbols simultaneously with a common clock. The Zipper scheme implies that every carrier, in the total set of carriers in the DMT signal, is exclusively chosen to be used for either the up-stream or the down-stream direction. When all transmitters are time synchronized, the near end cross-talk (NEXT) and near end echoes injected into the received signal are orthogonal to the desired signal. To ensure the orthogonality between the signal and all the noise sources originating from DMT signals in the opposite direction, the guard time with cyclic extension of the symbols between consecutive symbols must be dimensioned for the maximum propagation delay of the channel. Further, the size of the guard time is minimized by applying timing advance.

Figure 1 depicts how two VDSL systems sharing the same cable are

affected by line attenuation, near end echo and cross-talk.

When timing advance is used, all transceivers start the transmission of each frame at the same time. There are three types of signals that affect the length of the cyclic extension in each frame: the received signal, the echo-signal due to imperfect balance of the hybrid and impedance discontinuities in the line, and finally the NEXT signal. Figure 2 shows sampling at the VTU-O side of received frame disturbed by frames from near-end transmitters.

The orthogonality between the desired part of the received signal and the disturbances is preserved if each sampled DMT symbol is disturbed by a single frame from each one of the near-end transmitters. As a consequence, to preserve orthogonality, the cyclic extension has to be dimensioned to cover all impulse responses of the line, the echoes, and the NEXT.

The management of capacity split between up-stream and down-stream is performed by the assignment of individual carriers for both directions. For example, if fully symmetric services are desired, even carrier indexes can be assigned for up-stream and odd for down-stream. Similarly, for an asymmetric 8:1 split each ninth carrier can be assigned for the up-stream and the others for the down-stream. However, for the sake of spectral compatibility with other existing and future systems operating in the same cable, alternative carrier assignments could be considered.

The transmission and reception of symbols is performed simultaneously at both ends by the VTU-O and by the VTU-R. For down-stream transmission the bit stream is encoded by the VTU-O transmitter into a set of quadrature amplitude modulated (QAM) sub-symbols, where each QAM sub-symbol represents a number of bits determined by the signal-to-noise ratio (SNR) of its associated down-stream sub-channel, the desired overall error probability, and the target bit rate. The set of sub-symbols is then input as a block to a complex-to-real discrete Fourier transform (IDFT). Following the IDFT, a cyclic prefix is prepended to the output samples to eliminate intersymbol interference, and a cyclic suffix is appended to the output samples to maintain orthogonality between the desired signal and near-end

distorting signals, and the result is converted from digital to analog format and applied to the channel. At the VTU-R receiver, after analog-to-digital conversion, the cyclic prefix and suffix are stripped, and the samples are transformed back to the frequency domain by a DFT. Each output value used for down-stream transmission is then scaled by a single complex number to compensate for the magnitude and the phase of each down-stream sub-channel's attenuation, and a detector decodes the resulting symbols. The multiplication with this set of complex numbers, one per down-stream sub-channel, is called frequency-domain equalization (FEQ). Figure 3 shows a block diagram of a DMT transmitter and receiver pair, assuming a noiseless channel.

In steady-state, the subchannel SNRs are monitored in a data-driven manner by the VTU-R during down-stream symbol periods, and the bit distribution is modified as necessary at the VTU-O to optimize system performance. Upon detecting a degradation or improvement in one or more sub-channel SNRs, the VTU-R computes a modified bit distribution that better meets the desired error performance. Depending on the SNR of a degraded sub-channel, some or all of its bits may be moved via a *bit swap* algorithm to one or more other sub-channels that can support additional bits. The bit distribution change is reported to the VTU-O, where it is implemented.

For up-stream transmission, the roles of the VTU-O and VTU-R are reversed, that is, transmission and reception is performed on the up-stream set of sub-channels and the operations described above is the same.

The frequency range from zero to 11.04 MHZ shall be partitioned into 2048 sub-channels. The Nyquist carrier (sub-channel 2048) and the dc carrier (sub-channel 0) shall not be used for data.

Transmission may occur on up to 2047 sub-carriers, although those sub-carriers overlapping the POTS and ISDN bands and amateur radio frequency bands are typically not used in the default configuration. The lowest sub-channel available to support data transmission is dependent on the POTS/ISDN splitter design.

The frame format of Zipper consists of two parts; the DMT symbol, and the cyclic extension. The orthogonality is maintained between the received signal and disturbing DMT signals transmitted in the opposite direction if they are sufficiently aligned in time. This requirement is fulfilled by the use of a cyclic extension of the DMT symbol and the use of timing advance (TA). For the ease of description the cyclic extension can be divided into a cyclic prefix and a cyclic suffix part, where the suffix part is greater than or equal to the propagation delay of the channel and the prefix part is greater than or equal to the guard time needed to eliminate inter-symbol interference. Figure 4 illustrates the frame format for zipper.

When timing advance is used the transmitters all start transmitting at the same time. The suffix part of the cyclic extension can be treated as an extra guard time required to maintain orthogonality between the up and down-stream channels along the wire line. To fulfil the orthogonality requirement at the receiver, the cyclic extension (prefix+suffix) also has to cover the impulse response of the NEXT and the echo signal.

The first L_{cs} samples of the IDFT output are appended to the block of 4096 time-domain samples x_k . The last L_{cp} samples of the IDFT output shall be prepended to the block. The frame of samples is then read out to the digital-to-analog converter (DAC) in sequence. That is, the subscripts k of the DAC samples in the sequence are $(4096-L_{cp}),\ldots,4095,0,1,\ldots 4095,0,1,\ldots(L_{cs}-1)$.

The length of the cyclic extension (L_{cp} and L_{cs}) is typically a programmable entity set by the network operator.

In order to maximize high duplex efficiency, timing advance can be used so that the VTU-O transmitters and the VTU-R transmitters start transmitting each DMT frame at the same time. During the reception, a DMT symbol is only disturbed by single symbols, not affected by IFI, in the other direction due to the cyclic extension.

Zipper is a duplexing scheme based on the Discrete Multitone Modulation (DMT) line-coding technique and was invented at Telia Research in 1995. A patent

file (Kgp 86/95, Case 453) was registered at 950808. Zipper is currently a strong candidate to become the VDSL standard.

In certain situations it may be difficult due to practical reasons, or otherwise undesirable, to provide and maintain time synchronization between all transmitters in the same binder group. It is therefore desirable to provide an option for Zipper modems to operate in a non-synchronized mode, where only pairwise synchronization is maintained between a VTU-O and VTU-R pair. This option in the main claim of the patent. Thus, the presented invention is to allow different users to transmit time-asynchronous DMT frames in the same binder group. However, although this is always possible, a noticeable performance penalty due to increased NEXT is to be expected in many situations. One possible method to mitigate this is to use pulse shaping of the DMT frames prior to transmission and additional pulse shaping in the receiver. The usage of pulse shaping at the transmitter also results in a higher suppression of the sidelobes of the DMT signal spectrum and provides possibilities of higher spectral compability with other systems. Two examples of such systems are ADSL and CAP-VDSL.

When transceivers operating on different pairs in the same binder group are asynchronous, interference from NEXT will be introduced since the NEXT becomes non-orthogonal and therefore degrades the performance. The reason for the NEXT becoming non-orthogonal is that the received and sampled DMT frame will include NEXT from two consecutive DMT frames which are discontinuous as depicted in Figure 5.

In order to be able to operate in a non-synchronized mode it is strongly recommended to suppress the NEXT by narrowing its out-of-band spectrum which interferes with the spectrum of the received signal. This can be obtained by pulse shaping the DMT frame before transmission.

Pulse shaping a DMT frame is performed by forming pulse-shaped wings, e.g. from a raised cosine pulse, in the cyclic extensions of the frame as shown in Figure 6.

With the pulse shaping a continuous phase is created between succeeding frames and which suppresses the NEXT-interfering subcarriers' side lobes.

The pulse shaping operation is performed at the transmitter after the cyclic extension is added to the symbol and before the digital to analog conversion (DAC) is performed. The position of the pulse shaping unit is depicted in Figure 7.

Windowing the received DMT frame as shown in Figure 8 will suppress the non-orthogonal NEXT further. The windowing is performed by multiplying μ samples at both the beginning and end of the $2N+\mu$ block of samples. The $\mu/2$ samples from both ends is folded and added to the 2N remaining block of samples at the opposite ends as shown in Figure 8. As with the pulse shaping of the DMT frames in the transmitter the windowing in the receiver will create a continuous phase of the non orthogonal NEXT signals. The positioning of the windowing is shown in Figure 8.

The combined effect on the non-orthogonal NEXT of pulse shaping the DMT-frame in the transmitter and windowing the received frame in the receiver is shown in Figure 9. It shows the signal energy, NEXT reference signal without pulse-shaping and windowing, NEXT signal after pulse-shaping and windowing and the FEXT signal at each subcarrier. As seen in the figure, more than 25 dBm/Hz further suppression can be obtained by both pulse shaping and windowing.

CLAIMS

1. A telecommunications transmission system using zipper having at least two VDSL systems, each of said VDSL systems comprising a pair of zipper modems communicating over a cable transmission path, said at least two VDSL systems employing a common cable, characterised in that said telecommunications transmission system is adapted to:

- handle zipper transmissions transmitted over said common cable;
- at least partly mitigate NEXT; and
- permit transmissions in a first VDSL system which are asynchronous with transmissions in at least a second VDSL system.

2. A telecommunications system as claimed in claim 1, characterised in that DMT frames are pulse shaped prior to transmission.

3. A telecommunications system as claimed in claim 2, characterised in that said pulse shaping produces an improved suppression of side lobes of said DMT's spectrum.

4. A telecommunications system as claimed in either claim 1, or 2 characterised in that said pulse shaping is produced by forming pulse shaped wings on a DMT frame in cyclic extensions of the DMT frame.

5. A telecommunications system as claimed in claim 4, characterised in that said pulse shaped wings are in the form of a raised cosine pulse.

6. A telecommunications system as claimed in any of claims 2 to 5, characterised in that said pulse shaping is performed at a transmitter after addition of a cyclic extension to a symbol and prior to digital to analogue conversion.

7. A telecommunications system as claimed in any of claims 1 to 6, characterised in that a DMT signal received by a receiver is windowed to further reduce NEXT.

8. A telecommunications system as claimed in claim 7, characterised in that said windowing is performed by:

- multiplying μ samples at the beginning and end of a block of 2N+μ samples;

- folding and adding μ/2 samples from the beginning of the 2N+μ block of samples to the end of the 2N remaining samples; and

- folding and adding μ/2 samples from the end of the 2N+μ block of samples to the beginning of the 2N remaining samples.

9. In a telecommunications transmission system using zipper and having at least two VDSL systems, each of said VDSL system comprising a pair of zipper modems communicating over a cable transmission path, said at least two VDSL systems employing a common cable, a method of transmission characterised by permitting zipper transmissions of said first and, at least, said second VDSL transmission systems, to be transmitted over said common cable, where transmission in said first VDSL system are asynchronous with zipper transmission in said second VDSL system and in which the effects of NEXT are, at least partly, mitigated.

10. A method, as claimed in claim 9, characterised by pulse shaping DMT

frames prior to transmission.

11. A method, as claimed in claim 10, characterised by said pulse shaping producing an improved suppression of side lobes of said DMT's spectrum.

12. A method as claimed in either claim 10, or 11 characterised by forming pulse shaped wings on a DMT frame in the cyclic extensions of the DMT frame.

13. A method as claimed in claim 12, characterised by forming said pulse shaped wings as a raised cosine pulse.

14. A method as claimed in any of claims 10 to 13, characterised by performing said pulse shaping at a transmitter after addition of a cyclic extension to a symbol and prior to digital to analogue conversion.

15. A method as claimed in any of claims 9 to 14, characterised by windowing a DMT signal received by a receiver to further reduce NEXT.

16. A method as claimed in claim 15, characterised by using the following steps to perform said windowing:

- multiplying μ samples at the beginning and end of a block of 2N+μ samples;

- folding and adding μ/2 samples from the beginning of the 2N+μ block of samples to the end of the 2N remaining samples; and

- folding and adding μ/2 samples from the end of the 2N+μ block of samples to the beginning of the 2N remaining samples.

17. A transmitter, characterised in that it is adapted for use with a telecommunications system as claimed in any of claims 1 to 8, or to use a method as claimed in any of claims 9 to 16.

18. A receiver, characterised in that it is adapted for use with a telecommunications system as claimed in any of claims 1 to 8, or to use a method as claimed in any of claims 9 to 16.

ABSTRACT

Improvements In, or Relating to, VDSL

Zipper is a time-synchronized frequency-division duplex implementation of discrete multi tone (DMT) modulation. Two communicating Zipper modems transmit DMT symbols simultaneously with a common clock. The Zipper scheme implies that every carrier, in the total set of carriers in the DMT signal, is exclusively chosen to be used for either the up-stream or the down-stream direction. When all transmitters are time synchronized, the near end cross-talk (NEXT) and near end echoes injected into the received signal are orthogonal to the desired signal.

The present invention provides s telecommunications transmission system using zipper and having at least two VDSL systems. Each of VDSL system comprises a pair of zipper modems communicating over a cable transmission path. The two VDSL systems employing a common cable. The telecommunications transmission system is adapted to:

- handle zipper transmissions transmitted over the common cable;
- at least partly mitigate NEXT; and
- permit transmissions in a first VDSL system which are asynchronous with transmissions in a second VDSL system.

1/9

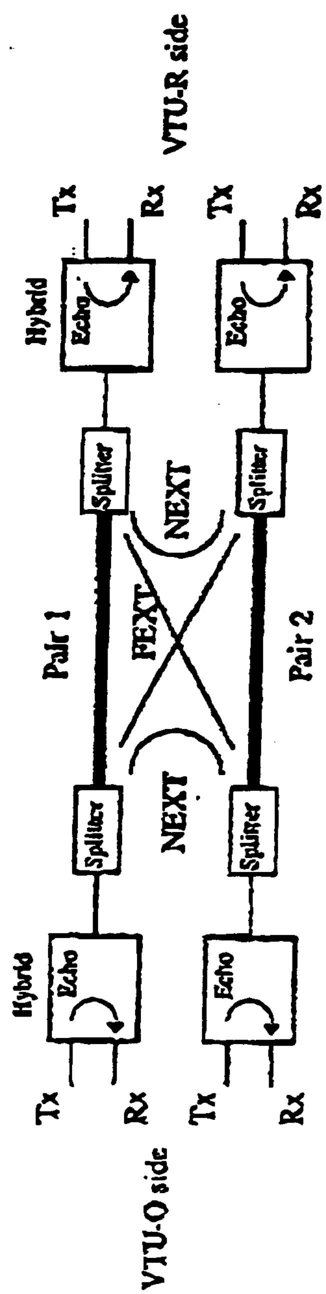

VTU-R side
Tx
Rx
Tx
Rx
Hybrid
Echo
Echo
Splitter
Splitter
NEXT
FEXT
Pair 1
Pair 2
NEXT
Splitter
Splitter
Hybrid
Echo
Echo
Tx
Rx
Tx
Rx
VTU-O side

Fig. 1

2/9

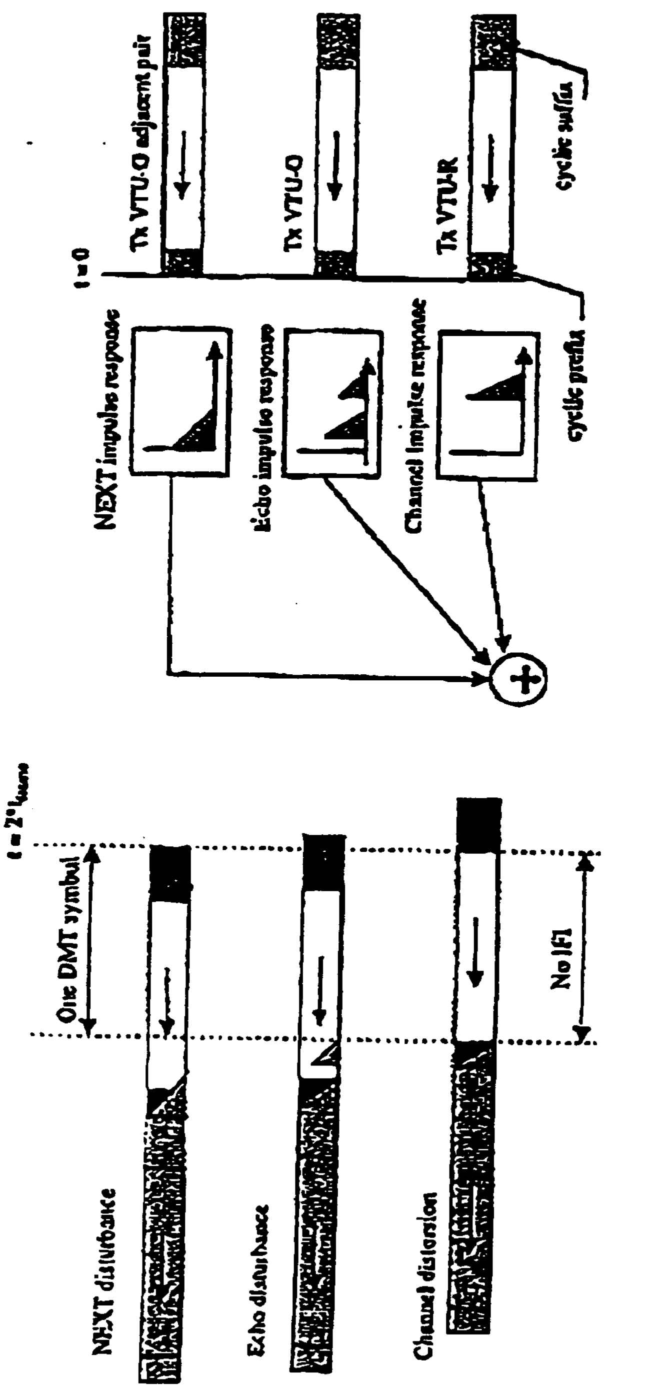

Tx VTU-O adjacent pair
Tx VTU-O
Tx VTU-R
cyclic suffix
t = 0
NEXT impulse response
Echo impulse response
Channel impulse response
cyclic prefix
One DMT symbol
No ISI
NEXT disturbance
Echo disturbance
Channel distortion

Fig 2

3/9

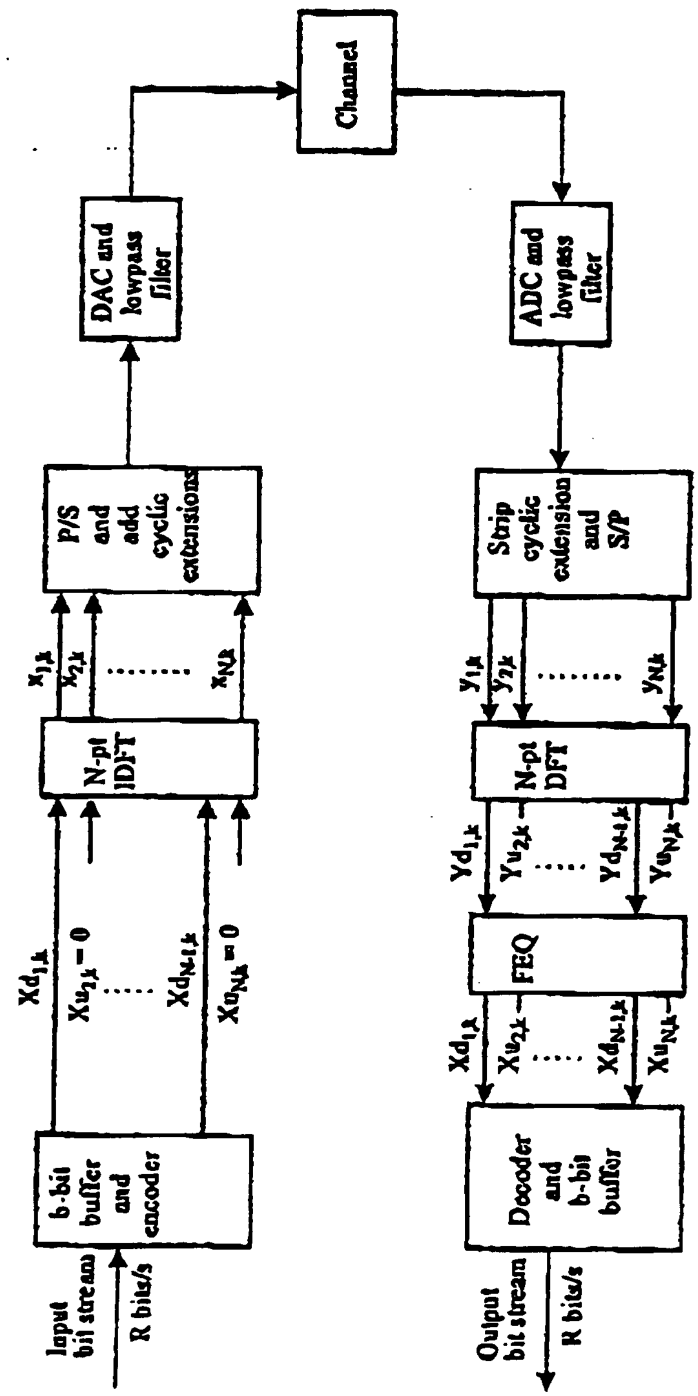

Channel
DAC and lowpass filter
ADC and lowpass filter
P/S and add cyclic extensions
Strip cyclic extension and S/P
N-pt IDFT
N-pt DFT
FEQ
b-bit buffer and encoder
Decoder and b-bit buffer
Input bit stream R bits/s
Output bit stream R bits/s

Fig 3

A19

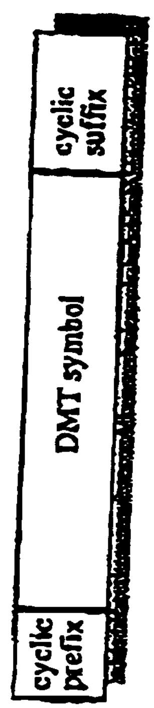


Fig 4

5/9

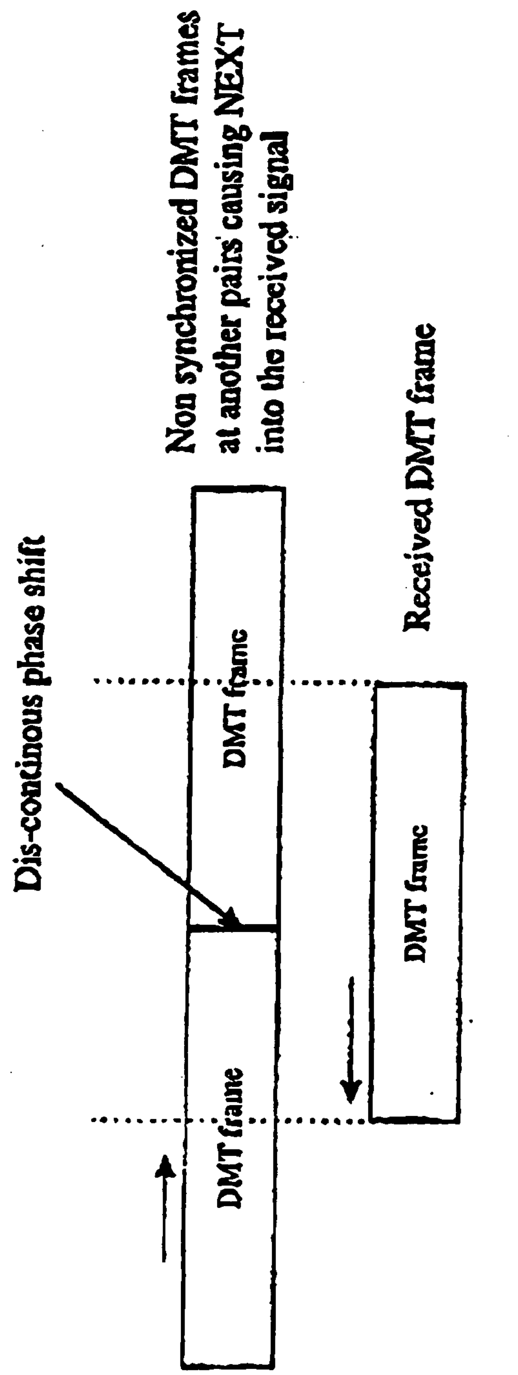

Non synchronized DMT frames
at another pairs causing NEXT
into the received signal
Dis-continous phase shift
DMT frame
DMT frame
Received DMT frame
DMT frame

Fig 5

6/9

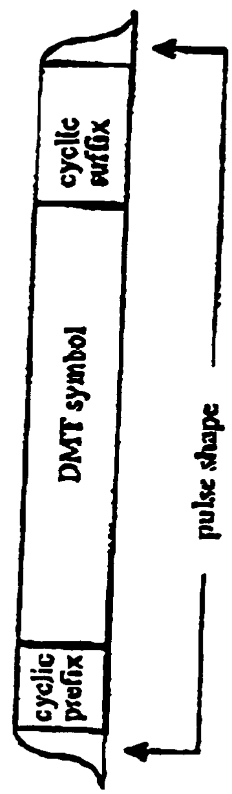


Fig. 4

7/9

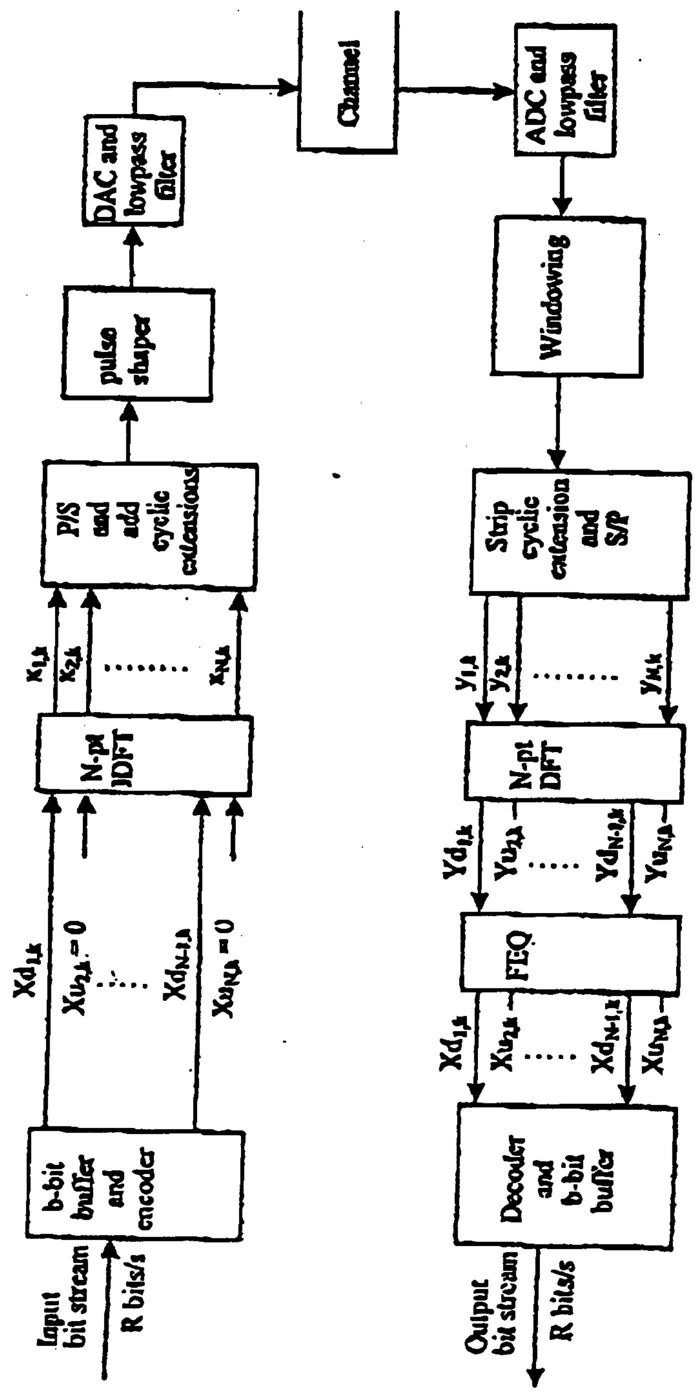

Input bit stream
R bits/s
b-bit buffer and encoder
$Xd_{1,k}$
$Xu_{2,k} = 0$
$Xd_{N-1,k}$
$Xu_{N,k} = 0$
N-pt IDFT
$x_{1,k}$
$x_{2,k}$
$x_{N,k}$
P/S and add cyclic extensions
pulse shaper
DAC and lowpass filter
Channel
ADC and lowpass filter
Windowing
Strip cyclic extension and S/P
$y_{1,k}$
$y_{2,k}$
$y_{N,k}$
N-pt DFT
$Yd_{1,k}$
$Yu_{2,k}$
$Yd_{N-1,k}$
$Yu_{N,k}$
FEQ
$Xd_{1,k}$
$Xu_{2,k}$
$Xd_{N-1,k}$
$Xu_{N,k}$
Decoder and b-bit buffer
Output bit stream
R bits/s

Fig. 7

8/9

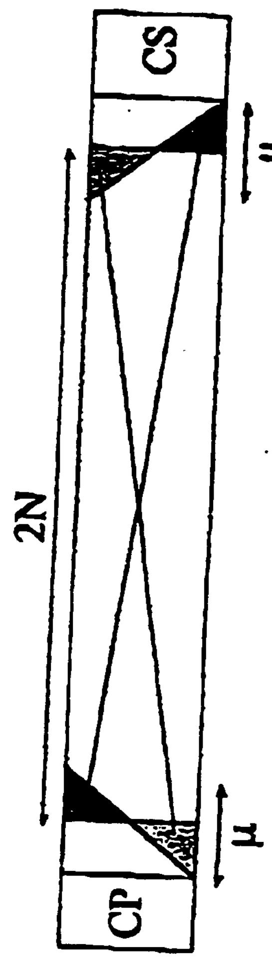
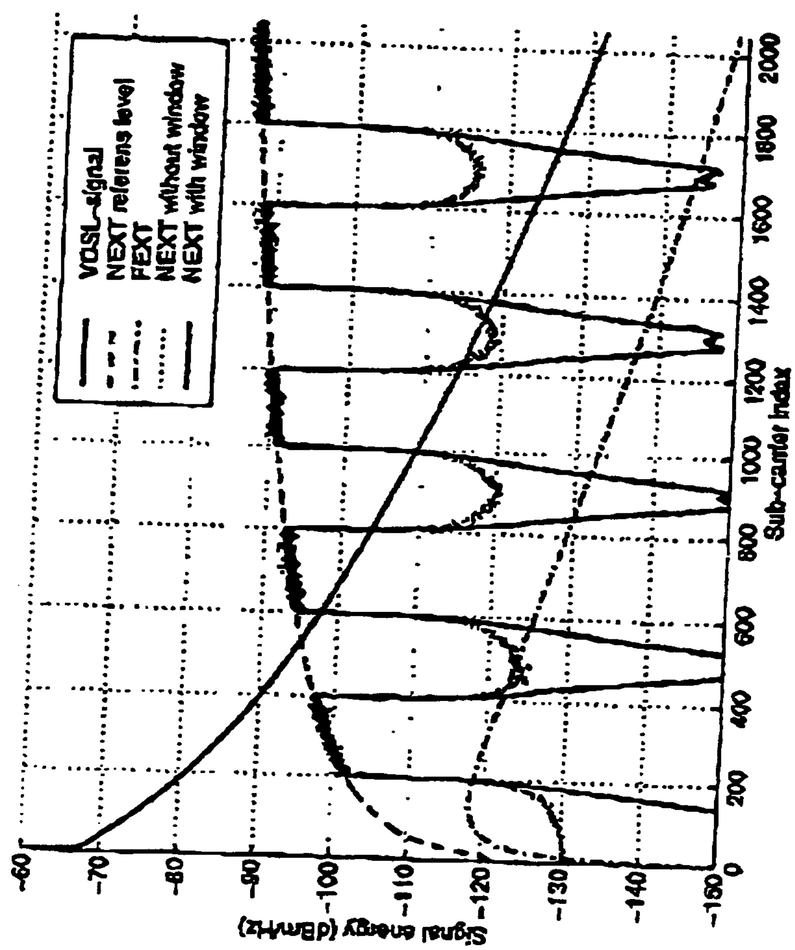


Fig 8

9/9

Fig. 9


VDSL-signal
NEXT referens level
FEXT
NEXT without window
NEXT with window
Sub-carrier index
Signal energy (dBm/Hz)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150